

COMBINE TAILINGS SENSOR SYSTEM

FIELD OF THE INVENTION

[0001] The present invention generally relates to agricultural combines or harvesters and, more particularly, to an apparatus for monitoring combine tailings.

BACKGROUND OF THE INVENTION

[0002] As an agricultural combine moves across a field, it cuts standing crop and feeds the severed crop materials to a threshing section of the combine. The threshing section of a rotary combine typically includes a threshing cylinder rotatably mounted within a foraminous housing. As the threshing cylinder rotates, the crop materials gently spiral rearwardly and grain is separated from the remainder of the crop materials. Material passing from the threshing cylinder gravitationally passes to a cleaning section of the combine for further processing.

[0003] The cleaning section of a rotary combine typically includes a pair of vertically spaced sieves. The sieves are horizontally oscillated causing clean grain to fall therethrough for collection. Normally, at least one of the sieves on the combine includes a plurality of "fingers" that are adjustable relative to each other such that the combine can operate in crop materials having different grains. A blower or fan directs air upwardly and across the sieves to further separate material other than grain from the materials passing from the threshing section.

[0004] As will be appreciated, heavier grain material falls through the sieves, is collected, and conveyed to a clean grain bin on the combine. Incompletely threshed grain, however, will not normally pass through the sieves and yet is too heavy to be blown out the rear of the combine with the chaff. These materials,

which include grain, are commonly referred to as "tailings". As an example, "tailings" include a fluffy or extremely light weight mixture of grain and mature vegetation on which the grain grows. In the case of wheat, barley and similar crop, tailings include the grain which remains attached to the fragments of the heads, while in the case of corn, tailings include kernels, which remain attached to a piece of cob. To enhance the effectiveness of the combine, the tailings are recycled by returning them to the threshing section for rethreshing as through use of a tailings elevator.

[0005] The volume or amount of tailings being recycled depends on the efficiency of the threshing and cleaning sections of the combine. Efficiency of the threshing and cleaning sections is determined by such factors as the clearances provided between the threshing cylinder and housing, threshing speed, the adjustment of the sieves, the output of the cleaning fan, and the volume of crop material input into the combine. If the volume or amount of tailings presented for return is excessive, the combine will tend to "plug up" with grain. That is, as the machine becomes full, the drive system used to transfer rotary power between components begins to slip thus presenting significant operating problems for the operator. When the combine does plug up, however, the operator needs to spend valuable harvesting time returning it to proper operating order. Besides the significant loss of valuable harvesting time, when a combine plugs up serious and costly damage can occur to the combine.

[0006] To solve the problem of excessive tailings, the operator can reduce ground speed of the combine, thus presenting less crop material for threshing. As will be appreciated, this is not a feasible solution to the problem because slowing the speed of the combine likewise means less efficiency. Alternatively, the operator can adjust the sieves to reduce the volume of tailings. Sieve adjustment, however, is a subjective process for the operator. That is, the operator can not be sure whether the adjustment chosen is correct before the machine is again plugged up. Alternatively, if the adjustment is incorrect, and although the tailings volume may be reduced, there may be significant contamination of the clean grain

as a result of the sieves being incorrectly adjusted. Moreover, adjustment of the sieves is a time consuming process which may or may not be required depending upon several factors including the dryness of the crop material.

[0007] To solve this problem, a system of monitoring and displaying the quantity of tailings was disclosed in U.S. Patent Number 6,053,811. In this system, a sensing device located near the tailings auger at the rear of the combine generated a signal indicative of the quantity of tailings that were created. An electronic display showed the quantity of tailings on a display for the operator to monitor.

[0008] The tailings sensing device was susceptible to vibration and other sources of electrical signal noise, however, making it difficult to provide a steady reading indicating the actual tailings volume.

[0009] What is needed is an improved system of measuring the quantity of tailings that is less susceptible to vibration, uneven tailings flow and other noise sources than previous sensing devices.

SUMMARY OF THE INVENTION

[0010] In view of the above, and in accordance with a first aspect of the invention, there is provided a system for sensing the presence of tailings in a combine, including a sensor configured to generate a signal indicative of a flow rate of tailings, and a first electronic module coupled to the sensor for removing transient high excursion noise from the signal, for example by clipping transient excursion noise.

[0011] The sensor may be configured to be disposed adjacent a laterally-extending tailings auger between adjacent sidewalls of a combine.

[0012] The system may further include a second microcontroller module configured to receive the filtered signal and display it.

[0013] The first module may be configured to notch filter the signal at a natural frequency of the tailings auger and clip positive-going sensor signal excursions.

[0014] The first module may be configured to low-pass filter the clipped sensor signal.

[0015] The second module may be configured to display the low-pass filtered signal.

[0016] The first module may be configured to digitally identify local minima of successive sensor signal samples.

[0017] The noise may be removed in a first phase of noise removal by passing the sensor signal through a band-stop filter (or notch filter) to filter out noise components of the signal that are generated by the auger at the auger's rotational frequency.

[0018] Additional noise may be removed in a second phase of noise removal by determining when the first phase signal changes states from being near a local minimum value, to a magnitude away from a local minimum value. The system may deem significant excursions away from the local minimum to be noise and removes these noise excursions away from the local minimum from the first phase signal.

[0019] Even more noise may be removed in a third phase of noise removal by low-pass filtering the second phase signal to smooth the output and provide a more gradual signal transition.

[0020] These and other objects, advantages and aspects of the invention will become apparent from the following description. In the description, reference is made to the accompanying drawings which form a part hereof, and in which there is shown a preferred embodiment of the invention. Such embodiment does not

necessarily represent the full scope of the invention and reference is made therefore, to the claims herein for interpreting the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] **FIGURE 1** is fragmentary side elevational view of an agricultural combine embodying principles of the present invention;

[0022] **FIGURE 2** is an enlarged fragmentary cross-sectional view taken along line 2--2 of **FIG. 1**;

[0023] **FIGURE 3** is a sectional view taken along line 3--3 of **FIG. 2**;

[0024] **FIGURE 4** is a schematic representation of the electronic circuit that monitors the tailings sensor filters the output and displays the results.

[0025] **FIGURE 5** is a schematic representation of two of the microcontroller modules of **FIG. 4**.

[0026] **FIGURE 6** is a software flow chart of the process of reading the sensor, filtering the signal and displaying the result performed by the two microcontroller modules

[0027] **FIGURE 7** is a graph of the sensor signals produced at each stage in the processing shown in **FIG. 6**.

[0028] **FIGURE 8** is a state diagram of the second filtering step **606** of the program executed by microcontroller module **86** that performs three of the filtering steps shown in **FIGURE 6**.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

[0029] While the present invention is susceptible to being embodied in various forms, there is shown in the drawings a presently preferred embodiment hereinafter described. It should be understood that the present disclosure is to be considered as but one example of the invention, provided in sufficient detail for

those skilled in the art of agricultural combine manufacture to construct. It is not intended to limit the invention to the specific embodiment illustrated.

[0030] Referring now to the drawings, wherein like reference numerals refer to like parts throughout the several views, there is shown in **FIG. 1** a self-propelled agricultural harvester or combine **10**. The combine **10** is preferably of the type marketed by the assignee as its AFX-8010 combine but it should be appreciated that the teachings of the present invention are equally applicable to other forms of agricultural harvesters without departing or detracting from the spirit and scope of the present invention. Combine **10** includes a body or housing **12** carried on a frame or a chassis **14** which is supported for movement across a field by wheels **16**. The housing **12** includes parallel side walls **15** and **17** defining an enclosure therebetween. As is conventional, the combine is powered by an engine (not shown) and controlled from an enclosed operator station **18** arranged toward a forward end of the chassis or frame **14**.

[0031] A crop harvesting apparatus or header **20** and an infeed mechanism **22** are arranged toward a forward end of the combine beneath the cab enclosure **18**. As is well known, the harvesting apparatus or header **20** cuts and harvests the crop materials and feeds the severed crop materials to the infeed mechanism **22** as the combine is driven across a field. The infeed mechanism **22** receives crop materials from the header assembly **20** and directs them rearwardly to a threshing section **24** on the combine **10**.

[0032] In the illustrated form of the invention, the threshing section **24** is mounted within the housing **12** between the walls **15** and **17** and includes a rotor assembly **26**. The rotor assembly **26** is preferably configured as a single unit that threshes and separates the crop materials presented thereto into grain and material other than grain. As schematically represented in **FIG. 1**, the rotor assembly **26** comprises an elongated and generally cylindrical member **28** in the form of a rotor casing or cage having a rotor **30** mounted for rotation therein and about a fixed axis **32**. Between the upstream and downstream ends of the rotor

assembly **26**, crop material is threshed repeatedly, but gently, as it spirals around the single large diameter rotor **30** and grain is permitted to pass through the foraminous threshing cage **28**. In a conventional manner, suitable instrumentalities mounted on the periphery of the rotor **30** cooperate respectively with the rotor casing or cage **28** to thresh the crop materials such that most of the grain will be separated and propelled downwardly through the housing.

[0033] Threshed materials passing outwardly from the rotor assembly **26** gravitationally move and are received at a cleaning section **40** also arranged within the body or housing **12** of combine **10**. The purpose of the cleaning section **40** is to remove chaff and tailings from the threshed materials received from the rotor assembly **26**.

[0034] The cleaning section **40** includes a cleaning fan **42** and preferably two cleaning sieves **44** and **46**. Each sieve **44**, **46** is generally rectangular in configuration and extends in a fore-and-aft direction beneath the threshing section **24** and between the side walls **15**, **17** of housing **12**. During operation of the combine, the cleaning fan **42** directs a forceful stream of air upwardly through and across the top surface of the generally rectangular sieves **44** and **46**. As the materials fall from the rotor assembly, chaff, tailings and material other than grain is blown rearwardly under the influence of the cleaning fan **42**. The chaff and other light residue materials is entrained in the air stream of fan **42** and blown out the rear end of the combine.

[0035] To enhance versatility of the machine, and as is well known in the art, one of the sieves **44**, **46** preferably includes a plurality of adjustable fingers (not shown) arranged in a well known and cooperative relationship relative to each other such that the permeability of the sieve is adjustable depending upon the crop being harvested. Clean grain gravitationally passes through the sieves **44**, **46** and is collected in a clean grain collection area **48**. A clean grain elevator **50** moves the clean grain from the area **48** to a clean grain storage bin **52** preferably mounted on the frame or chassis **14** of the harvester.

[0036] Tailings, including grain which is only partly threshed, will not pass through the sieves **44**, **46**. Because they are too heavy to be blown out with the chaff under the influence of the cleaning fan **42**, the tailings pass from the cleaning section **40** to a tailings section **56** on the combine. The purpose of the tailings section **56** is to return tailings to one of the threshing section **24** or cleaning section **40** for rethreshing and, thus, recapturing of the grain carried with the tailings.

[0037] As shown in **FIGS. 1** and **2**, the tailings section **56** of the combine is arranged in predetermined relation relative to the threshing and cleaning sections **24** and **40**, respectively, and includes a tailings auger **58** arranged in combination with a tailings pan **60**. In a preferred form, the tailings auger **58** includes an elongated driven auger screw **62** that rotates about an axis **63** and extends transversely across the entire width of the sieves **44** and **46** in generally parallel relation. The auger screw **62** is mounted adjacent and in operative relation with the tailings trough or pan **60** to move the tailings toward one side wall of the combine. As is well known, the auger screw **62** includes flightings **65** extending along the axial length thereof for engaging and moving the tailings in one direction generally parallel with the axis **63** of the auger screw **62** and toward the right side of housing **12**.

The tailings auger **58** axially extends beyond the housing **12** through an opening or hole **64** defined in that side wall of the housing toward which the tailings are moved under the influence of auger **58**. The tailings are operatively delivered by the auger **58** to a tailings conveyor **66**. As shown is **FIGS. 1** and **2**, the tailings conveyor **66** is mounted outside or exteriorly of housing **12** in a housing **68**. The tailings conveyor includes three fans or blowers (**FIG. 1**).

[0038] As shown in **FIG. 2** to facilitate transference of tailings material between housing **12** and conveyor **66**, a tube-like coupler **70** is arranged in surrounding relation and extends axially along a lengthwise portion of the tailings auger **58**. As shown, coupler **70** defines an enclosed passage **72** that opens, at

one end, to wall **15** and, at the other end, to the inlet end of the tailings conveyor **66**.

[0039] The tailings section **56** of combine **10** further includes a tailings volume sensor **76** for sensing the volume of tailings being conveyed for reprocessing.

[0040] The auger trough or tailings pan **60** converges into the generally round tube-like coupler **70**. The convergence creates a restriction that limits the maximum capacity of the tailings conveyor **66**. Testing has revealed that measuring the volume of tailings material at this location is the best way to measure the capacity of the combine to handle tailings for rethreshing purposes. The tailings sensor **76** is preferably arranged adjacent to (or in) passage **72**.

[0041] As will be described in detail below, the sensor **76** of the present invention provides a visual indication of the operating efficiency of the combine **10** to the operator. The sensor **76** positively measures the volume or flow of tailings moving to the tailings conveyor **66** for rethreshing and provides an output signal proportional thereto.

[0042] As shown in **FIGS. 2** and **3**, the sensor **76** includes a sensing element **80** secured to the rear wall **81** and an actuator **82** operably associated with the sensing element **80** and configured to be positioned in close proximity to the periphery of flightings **65** on auger screw **62**. The sensing element **80** is capable of detecting rotation of actuator **82**. The preferred embodiment is a Hall Effect sensor of the type sold by Power Components of the Midwest. It may also be of a potentiometer type sold by Duncan Electronics, a division of BEI Sensors and Systems Company of Tustin, Calif. under Model No. 9810-678. Any apparatus capable of measuring the volumetric flow of tailings would be equally applicable to the present invention, such as a capacitive sensor for sensing the presence or absence of tailings, a force or strain sensor for detecting a force or load placed on components of the combine by the volume of tailings passing therethrough, a pressure sensor for sensing a pressure applied by the tailings against a structure,

a sensor for sensing the amount of work performed by the tailings auger proportional to the volume of tailings moved by the auger screw **62**, a hydraulic pressure sensor for sensing the hydraulic force applied to the auger, indicative of the applied load on the driving elements, an optical sensor to detect the flow of tailings, such as a light reflection or transmission sensor operative in visible, infrared, or ultraviolet ranges, or a radar sensor.

[0043] During operation of the harvester, the header **20** (**FIG.1**) reaps and rearwardly advances the crop material to the threshing section **24** of the combine **10**. Materials are passed outwardly from the threshing section **24** toward the cleaning section **40**. As the materials fall from the threshing section **24**, the air directed by the cleaning fan **42** separates the chaff from the heavier grain. Sieves **44** and **46** furthermore facilitate cleaning of the materials received from the threshing section **24**. Because the tailings are heavier they are not typically blown out the rear of the machine with the chaff. Instead, the tailings are moved to the tailing section **56** whereat the tailings auger **58** moves such tailings through the hole or opening **64** in the housing **12** to the tailings conveyor **66** for reprocessing so as to recapture the grain carried therewith.

[0044] As the tailings are moved to the right by auger screw **62** of the tailings conveyor, they are pressed against actuator **82** and deflect it to the right (in **FIG. 2**) as well. This deflection pivots the lower end of the actuator to the right, which rotates the sensing element **80**. The signal produced by the sensing element is generally proportional to the degree of deflection of the sensing element.

[0045] The force applied to the actuator **82** and thus the position of the actuator and the signal generated by the sensing element **80** are irregular. On each rotation of the auger screw **62**, the auger flighting **65** sweeps past the sensor **76** applying intermittent pressure against the actuator **82** at a frequency equal to the rotational frequency of the auger screw **62**--in this embodiment about 9.5 Hz. This pressure is not applied directly by the flightings **65** to the actuator **82**, since they do not contact the actuator, but is applied by the tailings. When

this cyclical pressure is applied to sensor **76**, the actuator **82** deflects momentarily. This once-every-revolution deflection of the actuator **82** generates a noise component in the sensor signal at the frequency of rotation of the auger screw **62**. When the flight passes the actuator **82**, the pressure applied by the auger screw **62** drops and the actuator **82** returns to its original position. The resulting once-every-revolution oscillation of actuator **82** produces a corresponding once-every-revolution oscillation in the signal produced by sensor **76**.

[0046] In addition to this cyclical noise component, there is a noise component generated by the uneven flow of tailings through the tailings auger **58**. The tailings typically include clods or chunks of plant matter and earth that jostle the actuator **82** as they pass through auger **58**. These chunks of matter hit the actuator **82**, causing it to bounce upward away from the tailings flow, and cause the sensor **76** to generate sudden transient signal spikes that almost immediately disappear, for once the chunks hit actuator **82**, they bounce off, continue through auger **58**, and the actuator **82** returns to its original position, riding along on the surface of the tailings stream.

[0047] These sudden, irregular, random and transient excursions of the sensor signal due to impacts against the actuator **82** provide a second source of noise to the signal since they do not truly indicate the level of tailings in the auger, merely the erroneous movement of actuator **82** up and away from the tailings.

[0048] **FIGURE 4** illustrates the control circuit **84** that processes the signal of sensor **76**. Circuit **84** includes a first microcontroller module **86** that is operatively coupled to sensor **76** to receive and process the sensor signal. A second microcontroller module **88** is cooperatively coupled to module **86** to receive the processed signal and transmit it to an electronic display **90**. Electronic display **90** is operatively coupled to the second module **88** to receive the processed signal and display it to the operator. A serial communication link **92** such as an SAE

J1939 CAN bus couples module **86** and **88** to transmit the processed signal as a series of digital packets.

[0049] Referring to **FIGURE 5**, each of modules **86** and **88** include a micro microprocessor (uP) **94** that is coupled to an I/O circuit **95**, to a random access memory (RAM) **96**, a read-only memory (ROM) **98**, and an intra-controller communications circuit **100** over data, address and control bus **102**. The ROM **98** stores programmed digital instructions that command processor **94**. The RAM **96** provides memory locations that are used by the processor **94** to store various data that it generates as it executes the programmed digital instructions stored in ROM **98**. Communications circuit **100** receives data in the form of digital values from processor **94** and transmits them in accordance with a predetermined communications protocol to the communications circuit of the other module in the form of digital data packets. The communications circuit is configured to provide bi-directional communications so that both modules **86** and **88** (see **FIG. 4**) can communicate one with the other. I/O circuit **95** preferably includes signal conditioning, analog-to-digital conversion and display driving circuitry for interfacing the modules with the outside world, and (in particular) with the sensor and the display.

[0050] The modules **86** and **88** are preferably Siemens microcontroller devices (Model No. 167) and associated circuitry. While this is the preferred embodiment, the processing described herein can be provided by any digital processor with associated RAM and ROM that is configured to receive a sensor signal and perform the steps or equivalent steps described herein. Furthermore, while the ability to communicate between two modules is desirable, one may use a single module that provides the same signal processing capability and preferably the same display-driving ability, thus obviating the need for a second module.

[0051] In operation, and as shown in **FIGURE 6**, module **86** first receives the raw signals from sensor **76** to which it is coupled (block **602**), it then notch (or

band stop) filters the signal (block **604**) in the first phase of noise removal. It then clips or attenuates the sudden upward excursions of the signal (block **606**) caused by sudden impacts with the actuator and the actuators swinging up above the level of the tailings in the auger in the second phase of noise removal. It then smooths the results of the second phase of noise removal by low-pass filtering the results of the second phase (block **608**). Finally, module 86 transmits the signal to module **88** (block **610**). Once module **88** receives the signal it transmits the signal to the visual display (block **612**)

[0052] These steps of noise removal and the resulting noise-reduced signal values can be seen in **FIGURE 7**. In **FIGURE 7**, the raw signal from the sensor is shown as first trace **702**. Second trace **704** shows the same signal after it has been notch or band stop filtered to remove the 9.5 Hz noise component. Note that there are still sudden upward, positive excursions or spikes **706** in the second signal generated by sudden impacts against actuator **82** sending it bouncing up away from the flow of tailings in the auger. The third trace **708** illustrates the sensor signal after the sudden upward excursions of the signal have been removed by module **86**. The final or fourth trace **710** illustrates the sensor signal after the third and final phase of noise removal—the step of low-pass filtering the results of the second phase to provide a smoothly changing, gradually rising and falling signal that most closely represents the flow of tailings through the auger of the tailings elevator.

Band Stop Filtering

[0053] In block **604**, the first phase of noise removal, module **86** notch filters the raw sensor signal to remove the noise generated by the rotating auger of the tailings conveyor. The rotational speed of the auger in the preferred embodiment is 580 rpm or about 9.5 Hz. The sensor signal resonates at this frequency causing significant noise. Module **86** includes stored digital instructions that operate on the received sensor signal to remove this fluctuating noise component.

[0054] In the preferred embodiment, a Chebyshev type II band stop IIR filter is used to eliminate the resonant frequency. The filter has pass bands below 7Hz and above 12 Hz, a stop band between 9Hz and 10Hz, and a sampling frequency 100Hz. This range allows for variation in auger speed and therefore changes in the resonant frequency of the noise. In order to reduce to order of the filter, the attenuation of the stop band is selected to be 5dB only and the pass band ripple is selected as 1dB. These attributes will, of course, vary depending upon the magnitude of the noise signal as well as its frequency. This step may be obviated by locating sensor **76** in a different orientation and different location that reduce or eliminate the noise component generated by the auger's movement.

Transient Filtering (clipping)

[0055] In block **606**, the second phase of noise removal, module **86** removes the noise component of the signal caused by the irregular flow of tailings kicking the actuator upward above the surface of the tailings by clipping these upward-going spikes.

[0056] This process is illustrated in the state-transition diagram of **FIGURE 8** in which the first state is the "not_local_min" state, the state in which the sensor signal is not at its local minimum. One reason being the actuator **82** being forced up in the air. This is shown in **FIGURE 7** as the spikes or peaks in traces **702**, **704**. The sensor **76** signal is shown as trace **708** in **FIGURE 7** after these spikes or peaks have been removed.

[0057] The second state is the state of "local_min" in which the sensor signal is found to be near the bottom (i.e. the minimum) of each of the spikes in trace **704**. When the signal is near its minima it is most accurate, since this is the point at which the actuator touches the top of the tailings flow, before it is again kicked up into the air by stray matter passing through the tailings elevator.

[0058] **FIGURE 8** illustrates the conditions that module **86** is programmed to check in each state and the actions that module **86** is programmed to take in each state to remove noise from the signal.

[0059] Before explaining the noise removal programming identified in **FIGURE 8**, we should first explain the forms of notation that the **FIGURE** uses. The notation "in[x]" where "x" is a number, means the magnitude of the notch filtered signal measured at time x. In short, this refers to the y value of trace **704** that is the input to this phase of noise removal. Thus, in[0], in[1], in[2], in[3], in[4], in[5], and in[6], refer to the last seven sensor signal readings, where in[0] is the most recent and in[6] is the oldest.

[0060] In the program described below, each time a new sensor signal value is generated by module **86** (typically once every ten milliseconds) module **86** also updates each of the in[x] variables to its new value, with in[6] receiving the previous value of in[5], in[5] receiving the previous value of in[4], in[4] receiving the previous value of in[3], in[3] receiving the previous value of in[2], in[2] receiving the previous value of in[1], in[1] receiving the previous value of in[0], and in[0] receiving the very latest sensor signal value. In this manner, each of the values is simultaneously updated on a predetermined interval, preferably about every ten to one hundred milliseconds.

[0061] The state transition diagram in **FIGURE 8** illustrates how module **86** determines the state of the sensor **76** signal. The "state" of the signal is defined by the conditional statements associated with each state and each state transition shown in **FIGURE 8**. The conditional statements include two parts: (1) a test of the sensor signal values, and (2) (a) a determination of the output signal, or (b) a change in the state of the system from local_minimum to not_local_minimum or vice versa.

[0062] There are only two states in the diagram, the local_minimum state **802** and the not_local_minimum state **804**.

[0063] Module **86** is configured to periodically determine whether there has been a transition from the not_local_minimum state to the local_minimum state. This determination is indicated by transition Statement 1. Module **86** is programmed to execute transition statement 1 every ten milliseconds.

```

[in[0]<800 & in[1]<800 & ...
in[2]<800 & in[3]<800 & ...
in[4]<800 & in[5]<800 & ...
in[6]<800 & ...
((in[0]+in[1]+in[2])/3 – in[3]>3) & ...
((in[4]+in[5]+in[6])/3 – in[3]>3)]
{min=in[3];}
(Statement 1)

```

[0064] The first four lines of Statement 1 check to see if the sensor signal is in a reasonable range by insuring that the last seven sensor signal readings were less than 800. The local minimum most likely will occur well below the full range of 1024 (the full range for this particular sensor) and certainly below the 80% value of 800. For this empirically determined reason, the signal is inspected to be sure it is below 800 before it returns to the local_minimum state. Module **86** will not transition to the local_minimum state if any of the signals are equal to or greater than 800.

[0065] The fifth and sixth lines of this statement check to see if the middle reading (in[3]) of the last seven readings is a local minimum. Module **86** does this by determining whether in[3] is three less than the average of three sensor readings before it (i.e. in[4], in[5], in[6]) and also three less than the average of the three readings after it (i.e. in[0], in[1], in[2]).

[0066] If all the conditions of lines 1-6 are true, module **86** transitions to the local_minimum state and sets the value of variable “min” to the value of in[3]. At this point the variable “min” now holds module **86**’s best estimate of the sensor reading.

[0067] While it is in the local_minimum state, module **86** keeps track of the sensor signal to see whether it continues falling lower toward an even lower minimum as indicated by Statement 2. This statement is only executed by module **86** when module **86** is in its local_minimum state.

[in[3]<min]{min=in[3]} (Statement 2)

[0068] The first clause in this statement commands module **86** to check whether the fourth oldest sensor signal reading is less than the current value of “min” (i.e. in[3]<min). If so, module **86** is commanded to set the variable “min” to this now-lower value. As the signal keeps dropping in the local_minimum state, module **86** revises the local minimum (“min”) downward as long as the sensor signal keeps dropping.

[0069] Ultimately the sensor signal will reach its lowest point, the point at which the sensor actuator rests on the tailings flow-passing by the sensor. It will then rise again when the actuator is hit by another clod of material, or when the tailings flow fluctuates upward.

[0070] Module **86** is configured to determine when this upward transition occurs and to change from the local_minimum state to the not_local_minimum state. Statement 3, which module **86** periodically executes while in the local_minimum state, performs this state-checking.

[(((in[0]+in[1]+in[2])/3<=in[3]) | ...
 ((in[4]+in[5]+in[6])/3<=in[3]))
 {out1=min; lastout=min;} (Statement 3)

[0071] In lines 1 and 2 of this statement, module **86** checks to determine whether the average of the first three sensor signal values (in[4], in[5], in[6]) or the average of the last three sensor signal values (in[0], in[1], in[2]) are less than or equal to the values of the middle sensor signal value (in[3]). If either of these

conditions exists, then at least some of the earlier or later sensor readings are lower than $in[3]$ and therefore $in[3]$ is no longer the minimum signal value. The signal is not at its local minimum.

[0072] If either of these conditions is true, then module **86** recognizes this fact and changes state. In line 3 of Statement 3, module **86** (1) sets the corrected sensor signal value (i.e. “out1”) to the last minimum value that module **86** found, (2) exits the `local_minimum` state, and (3) enters the `not_local_minimum` state, as indicated by the state diagram of **FIGURE 8**. Variable “out1” contains the intermediate sensor signal value after the spikes in the signal have been removed. It is shown in **FIGURE 7** as trace **708**, which has a stair-step-like shape. Each step in the out1 trace **708** occurs whenever module **86** changes the value of “out1”. These changes occur whenever module **86** transitions from the `local_minimum` state to the `not_local_minimum` state and sets “out1” equal to the latest value of “min” (see Statement 3). Stair step changes in the out1 signal may also occur while module **86** is in the `not_local_minimum` state and executes Statement 4.

[0073] In the `not_local_minimum` state, module **86** continues to monitor the sensor signal and calculate new, corrected values of the sensor signal. Statement 4 is the conditional statement executed by module **86** while it is in the `not_local_minimum` state.

```

      [(in[0]-in[1]<3 and in[0]-in[1]>-3 & ...
      in[1]-in[2]<3 and in[1]-in[2]>-3 & ...
      in[2]-in[3]<3 and in[2]-in[3]>-3 & ...
      in[3]-in[4]<3 and in[3]-in[4]>-3 |
      (in[0]<lastout)]
      {out1=in[0];lastout=in[0];}           (Statement 4)

```

[0074] In the `not_local_minimum` state, module continues to monitor the sensor signal to determine whether the sensor signal values are caused by actual

contact with the flow of tailings or not. If either condition exists, module **86** will output the current sample, `in[0]`, as the filtered result, `out1`.

[0075] The first condition (lines 1-4) is based on the assumption that only rapidly rising or rapidly falling sensor signal values result from the impact between the material and the rod. Whenever the sensor signal changes slowly, it should be considered as authentic and not noise.

[0076] To make this check, module **86** determines the rising and falling speed of the signal in lines 1-4 of Statement 4. In these lines, module **86**, checks to see whether each of the last five sensor signal values (`in[0]`, `in[1]`, `in[2]`, `in[3]`, `in[4]`) are all within three counts of each other. If the maximum difference between adjacent sensor signal values is less than 3, then the sensor signal is stable, changing slowly, and the latest value, "`in[0]`", is deemed to be correct. As shown in line 6, module **86** will output the current sensor signal value, "`in[0]`", as the filtered sensor signal value, "`out1`" (`out1=in[0]`).

[0077] The second condition is based on observations of the simulation. Whatever value the sensor indicates, if that value is lower than the last local minimum, it is the better guess of the actual sensor signal.

[0078] In line 5, module **86** checks the latest sensor value to see if it is lower than the last output value (`in[0]<lastout`) and, if true, updates the output signal in line 6 (`out1=in[0]`). The sensor signal value, whenever smaller than the output value (`out1`), should be closer to the true value provided by direct contact of the actuator with the tailings flow. Therefore, the output value (`out1`) should be updated to the current sample value (`in[0]`) right away.

[0079] Trace **708** in **FIGURE 7** illustrates the filtering process shown in the state diagram of **FIGURE 8**.

[0080] Referring now to **FIGURE 8**, at times **712**, **714**, and **716**, the sensor signal (**704**) drops below the previously determined output (**708**) and module **86** recalculates the output value, "`out1`", downward.

[0081] At times **718** and **720**, the sensor signal (**704**) reaches a local minimum and begins to rise, module **86** recalculates the output value, "out1" to equal that minimum, and waits for the sensor signal to drop back down again.

[0082] These two effects are a practical illustration of how module **86** functions using the statements shown in **FIGURE 8**.

Low-pass Filtering

[0083] In block **608**, module **86** performs the last step of sensor signal filtering. In this step, module **86** low-pass filters the stair-step-shaped output of the second filtering stage to smooth the output and provide a more gradually changing, and more realistic signal output, as indicated by the low-pass filtered signal shown in trace **710** of **FIGURE 7**.

[0084] In block **610**, module **86** is programmed to transmit the latest value of the fully filtered signal (i.e. trace **710**) to module **88**. In step **612**, module **88** transmits the latest value to the display.

[0085] From the foregoing, it will be observed that numerous modifications and variations can be effected without departing from the true spirit and scope of the novel concept of the present invention. For example, the functions described herein as being performed by each microcontroller module may be performed by on or more than one such modules. While the modules are shown as having four basic components, they may have more or fewer, and the claimed functions may be performed by one or may be distributed among more than one. While the sensor is shown as a mechanical device, other sensors are possible, such as capacitive sensors, mass flow rate sensors, linear movement sensors, and capacitive sensors.

[0086] It will be appreciated that the present disclosure is intended as an exemplification of the invention, and is not intended to limit the invention to the specific embodiment illustrated. The disclosure is intended to cover by the appended claims all such modifications as fall within the scope of the claims.